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MAKIRA FOREST

CONSERVATION-BASED CARBON-OFFSET PROJECT

BIOMASS PART-II

METHODOLOGICAL GUIDELINES FOR ESTIMATING AND MONITORING CARBON STORAGE

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1. INTRODUCTION

In application of the Kyoto Protocol's Clean Development Mechanism (CDM), PAGE-IRG is preparing a campaign to involve international investors in a Joint Implementation (JI) land-use project for financing long-term conservation of the Makira-Anjanaharibe-Sud forest corridor in exchange for greenhouse gas emissions abatement credits (Meyers and Berner 2001). The Makira-Anjanaharibe-Sud natural forest conservation and carbon sequestration effort is expected to provide a significant amount of fixed carbon already in the early implementation period of the project. Elevated amounts of fixed carbon are expected because biomass density is assumed to be quite high and regional deforestation at non-project sites is currently releasing large portions of stored carbon in biomass due to extensive slash and burn practices ("tavy"). The primary carbon comparison required for this type of project is between the area set aside for carbon sequestration and the land-use the forest would be converted to if the forests were not protected. PAGE-IRG is currently conducting a forest cover change study of the western Maroantsetra region that encompasses the Makira-Anjanaharibe-Sud corridor. This study is expected to provide regional and sub-regional deforestation rates.

A major constraint for elaborating a complete feasibility study of the forest-conservation-based carbon offset project at Makira is the lack of reliable data for estimating biomass and carbon storage. Moreover, if Malagasy forest carbon becomes an internationally traded commodity, then monitoring the amount of carbon fixed by the JI project will become a critical component of the new trading system. Hence, accurate and cost-effective methods for estimating and monitoring carbon storage need to be developed in Madagascar.

Estimating biomass at the scale of the Makira-Anjanaharibe-Sud forest corridor can either be based on available data and preliminary assumptions or can be achieved through intensive, costly research efforts. At this stage, PAGE-IRG conducted a preliminary biomass study based on the available IEFN data (DEF 1997). The study produced promising results with elevated biomass per hectare values but the variances were extremely high given the small sample size (Rakotomaro 2001 / Berner 2001a). Hence, it is clear that the forwarded biomass estimates from the existing IEFN data are not sufficiently accurate to permit the elaboration of a ready-to-finance implementation proposal of the Makira conservation and carbon offset project as demanded by potential investors. Since costly and time-consuming groundwork is not possible at this fundraising stage, PAGE-IRG is committed to provide a set of methodological guidelines intended to facilitate a cost-effective, precise and accurate accounting of carbon storage and monitoring for the future project.

2. BOTTLENECKS FOR ESTIMATING AND MONITORING CARBON STORAGE AT THE MAKIRA COMPLEX

Based on the experiences gained during the first-approximation assessment of biomass values based on the IEFN data (DEF 1996), a series of bottlenecks were identified. These bottlenecks present key issues for the carbon estimation and monitoring methodology proposed in this report.

2.1. Forest Stratification

Based on the natural disturbance dynamics and on the geological, pedological and hydrological variability, the forests of the Makira complex are structurally quite heterogeneous, as was confirmed during the two reconnaissance flights (Berner and Rarivoarivelomanana 2001, Berner 2001b and 2001c). These structurally heterogeneous forests are likely to display high variances of biomass and carbon pools. Hence, it is not desirable to simply extrapolate average hectare-value from field inventories for the entire area. For refining the extrapolation step from a biomass hectare value to the whole Makira complex biomass estimate it is absolutely necessary to subdivide the Makira forests into tracks of more homogenous forest strata.

An attempt at stratifying the forests according to different reflectance patterns, as they appear from Landsat TM images, was undertaken during the preliminary assessment of biomass. The method turned out to be quite unreliable because the observed reflectance patterns could not be attributed to differential forest structures with sufficient certainties. If this Landsat image based forest stratification approach is further pursued a ground-truthing characterization and calibration exercise will have to be built into the design.

Meanwhile, it is also conceivable to stratify the Makira forest complex using the black and white FTM aerial photos originally used for the establishment of the topographic maps. The limitation here is that the pictures were taken in the early sixties and that given the dynamics of the forests the spatial display of the strata may have changed substantially (cyclones, dry spells, fires).

The importance for developing a reliable stratification scheme for the Makira complex in conjunction with carbon assessment can not be emphasized enough. Given the general lack of quantitative forestry data for this region the need to collect more baseline data from satellite images, aerial photos, overflights and ground-truthing is eminent.

Ultimately, proper stratification allows an efficient distribution of sample plots and reduces the chance of over-sampling which would be very costly in large remote areas of the Makira Complex.

2.2. Sample Size of Field Inventory

The level of precision of a carbon inventories has a direct effect on costs and should be chosen with care. The level of precision should ultimately be chosen by the project sponsors and is typically set within plus or minus 10 percent of the mean with a 95 percent confidence level (Boscolo et. al 2000). However, a pragmatic compromise between cost and precision will always have to be found. At the Noel Kempff site in Bolivia, it was estimated that raising the precision level from plus or minus 10 percent of the mean to 5 percent would double the cost (Boscolo et al. 2000). Once the level of precision has been chosen (based on scientific criteria or based on a budgetary ceiling for set inventory cost or based on threshold given by the price paid for the offset), the sample size must be determined for each stratum and for each carbon pool. Finding the most cost-effective sample size is likely to imply an iterative analysis (hands-on adjustment).

As pointed out by MacDicken (1997), the different carbon pools have different variances and sample size will have to be adjusted for each carbon pool, (e.g., above-ground woody biomass, organic soil carbon, root biomass). In addition, it is standard procedure to determine sample size of field inventories by stratum. A stratum is considered here to be a definable, structurally homogenous forest unit, and the within stratum-variance is expected to be sufficiently low to reduce sample size to reasonable numbers. Engineering a proper stratification scheme is likely to offset the cost resulting from over-sampling large heterogeneous forests. For instance, the forest stratification of the carbon offset climate action project Noel Kempff includes coarse forest classes like "tall evergreen forest", "liana forest", "flooded forest tall", "flooded forest short", "mixed liana forest", and "burned forest" (Boscolo et al. 2000).

The difficulty for the Makira complex regarding sample size determination is twofold: a) no operational forest stratification scheme, even simple, has been developed and, b) no preliminary data is available, whatsoever, to estimate a variance at the stratum level and for each carbon pool (but see Rarivoarivelomanana 2001 for coarse biomass estimates). Without an estimate of variance the sample size can not be calculated and the inventory can not be budgeted properly. Much guesswork for the planning is needed. To overcome these difficulties it is standard procedure to install preliminary pilot studies aiming at providing estimates of variances for key strata and key carbon pools. This two-stage approach is reliable but requires also a two-stage financial planning. If organizational and time constraints do not permit a two-stage planning a best-guess, coarse budget plan based on different sample size scenarios may be proposed. In order to quantify economies of scale, Boscolo et al. (2000) grouped the main costs into fixed and variable costs. Variable costs are expenditures that depend on the number of plots and should be reported in costs per plot. Note that the variable costs related to field crew productivity vary by strata as a result of differential forest accessibility and structural complexity (e.g., surveying remote cyclone damaged forest at Makira).

To overcome the very real sampling accessibility issue at the Makira Complex, it is conceivable to design strata-level transect-plot-based sampling schemes based on accessibility masks. The idea is to exclude the most inaccessible zones from sampling within each stratum to account for costly logistical constraints. This approach creates a sampling bias because in a systematic design the plots should be set over the entire area of a stratum at a regular spacing along transects oriented in random directions. However, the proposed tradeoff between design rigor and inventory cost seems acceptable given the forest homogeneity within a stratum. Note that in general, the more accessible parts of forests (edges) are more impacted by humans and, hence, lower on standing biomass. Sampling based on an accessibility mask would therefore result in an overly conservative estimate of the stratum-level biomass. However, given that the entire area (all strata) retained for estimating the carbon pool (see point 5.1. below) excludes all areas of visible human activities one can assume that the edge effect bias is a non-issue.

2.3. Form Factor, Wood Density and Biomass Expansion Factor

If the above-ground trunk biomass component is assessed through standard dendrometric measurements including diameter and tree height the computed results provide accurate VOB values (volume over bark), provided the form factor is not biased. Form factors can be determined if destructive sampling is possible but the exercise is time consuming and costly if undertaken in a complex tropical forest. Alternatively, conservative approximation values from the literature can be taken.

The conversion of trunk volume values (VOB) to tree biomass values implies adjustments for living branch-, twig- and leaf biomass not accounted for during forestry-type inventories. Brown (1997) suggests the use of the following conversion formula: VOB*WD*BEF [(volume over bark)*(wood density)*(biomass expansion factor)]. Again, wood densities and biomass expansion factors can be determined in the field, provided destructive sampling is acceptable. For a selected number of commercially desirable species, wood density values are available in Madagascar. However, for the majority of the species no data exists. The same line of statements could be made for the branch-, twig- and leaf biomass. For these biomass pools no reliable data exists from Makira and, hence, no adjustments of the assumed FAO biomass expansion factor can be made. Destructive field assessment of branch-, twig- and leaf biomass is feasible but given the noise of such data the work is considerable.

2.4. Biomass Regression Equations

For the other above-ground biomass components usually not accounted for during forestry type inventories (pool wood with trees dbh < 10 cm, palms, vines, understory vegetation), a series of biomass regression equation are proposed by FAO (Brown 1997). These equations, however, are coarse and should possibly be adjusted for Makira. This would imply the collection of destructive field data and the subsequent elaboration of new biomass regression equations. This work is time consuming and would imply that the necessary budgets are available for such undertaken. If not, and given that these carbon pools constitute only a small fraction of the total carbon pool, it may be acceptable to rely on values proposed in the literature.

2.5. Below-Ground Biomass Assessment

Root biomass is an important carbon pool. However, its estimation, even at moderate levels of precision is time consuming and expensive. Since no information on root:shoot ratio is available for Makira the best possible estimates need to be drawn from the literature unless field research is undertaken. MacDicken (1997) states that root biomass carbon pools represent 10 to 40 % of total biomass. If no supporting data is available, it is necessary to account for root biomass using the most conservative figure within this large range of reported below-ground biomass values. For Makira no below-ground biomass data is available and in light of the drawback that working with conservative figure is likely to underestimate carbon storage figures massively, it may be advised to collect supporting data on root biomass.

2.6. Soil Carbon

A conservative figure of the soil carbon stock of a tropical forest soil is set at 20 percent of the above ground biomass carbon value. Soil carbon is partitioned in two types of carbon including organic and inorganic carbon (carbonate). In Eastern Madagascar with dominant crystalline parent material and high rainfall average soils contain inorganic carbon pools that can easily be neglected (in addition, the few marble deposits should be ignored). However, soil carbon backup data should be provided in order to allow making less conservative assumptions for its estimate.

2.7. Litter Crop Biomass

Litter crop includes fine litter and dead wood. Fine litter is reported by Brown (1997) to constitute < 5 % of the above ground biomass. These values should be tested for the Makira complex. Dead wood, in contrast, has more variance and varies from 5 to 40 % of the above ground biomass (Brown 1997). It is definitively recommended to assess the dead wood component for the Makira forest with specific studies.

3. SELECTION OF METHODOLOGIES FOR MEASURING AND MONITORING FOREST CARBON IN THE MAKIRA COMPLEX

The most common and well-tested methodologies currently used to estimate carbon in biomass and rates of annual carbon accumulation and loss in relation to forest management and forest dynamics include:

- Remote sensing,
- Modeling,
- Eddy covariance and,
- Field inventories (Clausen and Gholz 1998).

To create more accurate estimates, it is often necessary to use these methodologies in tandem. Used separately, however, it is evident that these methods would not be equally suited for assessing and monitoring carbon storage in conjunction with the Makira-Anjanaharibe-Sud Natural Forest Conservation and Carbon Sequestration Project. Bellow, find a brief listing of strengths and weaknesses for each individual method. Based on a dialectical comparison of strength and weakness for each method a suitability statement for the Makira reality is being formulated.

3.1. Remote Sensing

a) Strength

- Produces broad geographical range of information,
- Provides reasonable land cover information depending on size of pixel resolution (satellite) or scale of picture (aerial photo),
- Satellite images are the best means for monitoring spatial and temporal changes of regional forest cover changes ("tavy");
- Aerial photos provide useful landscape-level information for the assessment of forest stratification.

b) Weakness

- Does not produce accurate estimates of structural forest changes,
- Does not catch selective logging and associated damages well,
- Does not permit the assessment of the vertical distribution of the vegetation (cyclone prone forests),
- Does not capture the removal of understory vegetation well.

C) Relevance for the Makira carbon assessment

- Satellite images are of utmost relevance for assessing the project perimeter ("tavy" frontier),
- Likewise, satellite images are of utmost relevance for monitoring ground-cover change in time and space (deforestation avoidance),
- Vertical, geo-referenced aerial photos constitute a relevant tool for assessing forest stratification,
- Geo-referenced, oblique aerial photos from overflights are a useful tool for assessing boundaries of forest strata.

3.2. Modeling

a) Strength

- Produces useful estimates on carbon flow within the system,
- Permits the tracking of physiologic processes in forests (e.g., absorption and partitioning of solar radiation, canopy structure),
- Predicts growth and mortality over time given assumed environmental parameters,
- Estimates photosynthesis and transpiration rates of tree crowns, e.g., MAESTRO (Wang and Javis 1990) and BIOMASS (McMurtrie et al. 1990),
- Estimates carbon, nitrogen and water cycling across forest ecosystem, e.g., FOREST BioGeoChemical (Running and Gower 1991).

b) Weakness

- Implies initial assumptions on field parameters difficult to make in complex, little-known forest ecosystems, (e.g., forest cover, canopy structure, diameter frequency distributions, height distributions, growth patterns, mortality rates, nutrient and water regimes, light availability, within stand temperatures, leaf area index, photosynthetic and transpiration rates),
- Entails a fair amount of initial forest ecological field data not readily available from Makira,
- Involves a time-consuming field verification and model enhancement process, (i.e., iterative data-collection, model-verification and model-enhancement process).

C) Relevance for the Makira carbon assessment

- Modeling growth and mortality of individual trees, as well as forest dynamics of cyclone prone forests would be very useful for the long-term monitoring of the dynamics of the carbon storage at Makira,
- For the short-term assessment of carbon storage, modeling is not a powerful tool in light of the general lack of ecological field data.

3.3. Eddy Covariance [1]

a) Strength

- Allows direct measurement of whole-ecosystem net exchanges that enables the estimation of net gain and losses of carbon for forests,
- Permits the most accurate, instantaneous assessment of forest carbon balances of all methods.

b) Weakness

- Is an expensive methodology,
- Requires a high degree of technical training,
- There are significant differences in opinion in interpretation of eddy covariance results.
- Rain interferes with data collection,
- Equipment maintenance is problematic in remote sites.

C) Relevance for the Makira carbon assessment

- Given the sophistication of the method, eddy covariance is yet not a suitable option for Madagascar,
- In light of rapid technical development of this method, however, and taking the insights generated from the Amazon forests into account (Grace et al. 1995), it is important to keep eddy covariance measurements as a future tool for monitoring carbon into account.

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[1] **Eddy covariance or correlation: Method of measuring the net vertical exchanges of heat, water vapor, momentum, gases (CO_2) of the turbulent structures (eddies) caused by winds interacting with the forest canopy underneath.**

3.4. Field inventories for monitoring contents and fluxes of forest carbon

a) Strength

- Are derived from well-established inventory techniques used in forestry, ecology and soil sciences,
- Can be designed to complement existing data from forestry inventory that provide information on above-ground, coarse woody biomass,
- Results can easily be compared with other inventories conducted in other established carbon sequestration projects in the tropics,

b) Weakness

- Even if forestry data is available they need to be complemented by ecological inventories to assess the missing carbon pools,
- Unless costly research is undertaken to verify some key parameters for the carbon assessment they will have to be set based on assumption drawn from the literature:
  - below-ground biomass values, (i.e., coarse roots, fine roots, organic soil carbon, inorganic soil carbon),
  - wood densities,
  - form factor,
  - branch, twig and leave component of the woody biomass,
- Precision is achieved through large sample size and the different carbon pools are heterogeneous (differential variances),

C) Relevance for the Makira carbon assessment

- Based on the reliability of the methods and their wide use it is recommended to rely strongly on field inventories for the accurate assessment of carbon storage and fluxes.

3.5. Conclusions

As stated above, it is often more efficient to use these methodologies in tandem and it would be wrong to categorically discard the use of some of these methodologies for the Maskira project. Nevertheless, it is evident that modeling and eddy covariance are less suited for assessing and monitoring carbon storage at the Makira-Complex. At this stage, it is recommend to give emphasis to remote sensing for the assessment of forest strata and for the monitoring of land-use change. For the assessment of carbon storage and for the monitoring of carbon flux, the field inventory methodology based on permanent plots seems appropriate for Makira.

Although ground survey is retained as the preferred method to estimate forest biomass it is important to keep in mind that new remote sensing, cost-effective methods such as dual camera videography or radar technologies are being developed (Boscolo et al. 2000).

4. RELEVANT CARBON POOLS FOR WHICH VALUES NEED TO BE PROVIDED

A state-of-the-art assessment of forest-level biomass and carbon storage requires that the biomass of all forest components be estimated including:

- Above-ground biomass
- Below-ground biomass
- Soil carbon
- Dead plant mass including wood and litter crop

Above-ground biomass includes the living mass of trees, palms, tree-ferns, Ravenala, Pandanus, vines, shrubs, saplings, seedlings, herbaceous vegetation, epiphytes, etc., with leaves, twigs, branches, aerial roots, main bole, bark, etc. Below-ground biomass includes root biomass of all the living organisms mentioned above with the exception of epiphytes. Soil carbon is partitioned in two types of carbon including organic and inorganic carbon (carbonate). Dead plant mass includes dead boles (standing and down), branches, twigs and standing litter crop.

Simple dendrometric data (tree-level diameter and total height) as provided by research based on classical forest inventories produce coarse estimates of the living above-ground trunk biomass component. If no supporting ecological is collected, the biomass contribution of leaves, twigs and branches to the woody biomass component needs to be elucidated based on methodological assumptions drawn from the literature. The idea is to convert the trunk volumes into biomass and to inflate this value to take into account the other above-ground components of the woody biomass. Estimates of the three other components, (i.e., below-ground biomass, soil carbon and dead plant mass) need to be produced separately, either from the available literature or experimentally.

4.1. Above-Ground Woody Biomass

For all practicalities, measuring trees larger than a minimum diameter allows estimating volume over bark (VOB), and subsequently compute living woody biomass quite well without posing too many logistical problems. Conventional forestry inventories techniques using tree diameter down to 10 cm dbh provide a good baseline data set for estimating coarse woody biomass. The design can either be based on permanent plots or be plotless with marked centers or no markings.

Marked plots have the advantage to permit a site-specific monitoring in contrast to a statistical monitoring.

Trees with dbh < 10 cm and down to a minimal dbh (1 cm) or a minimal height (1 m) occurre in much higher numbers and need to be assessed with a nested design. Their biomass and carbon values need to be computed by means of regression equations that need to be calibrated experimentally if not available from the literature.

4.2. Above-Ground Understory Biomass

Above-ground understory biomass includes all plants that are not taken into account in the above-ground woody biomass component because of their small size, (i.e., saplings (< 1 cm dbh or < 1 meter height), seedlings, herbaceous plants, ferns, mosses etc. Estimating the biomass of this component includes destructive sampling in small plots.

4.3. Below-Ground Biomass

Root biomass is an important carbon pool that is difficult to estimate even at moderate levels of precision. Given, however, that there is no supporting data for the Makira Complex it will be necessary to produced baseline values through sampling.

4.3. Soil Carbon

Soil carbon constitutes a substantial fraction of the total carbon stock of a tropical forest. Soil carbon relevant for the Makira-Complex is limited to organic carbon. Soil carbon backup data should be provided.

4.4. Litter Crop

Litter crop includes fine litter and dead wood. Fine litter is readily collected in litter traps and although it constitute less than 5 % of the above ground biomass data should be collected at the Makira forest.

Dead wood may constitute a substantial fraction of the above-ground carbon stock of a tropical forest and varies from 5 to 40 % (Brown 1997). In order to narrow down the range it is recommended to investigate the dead wood fraction of the Makira Complex. In addition, and in conjunction with the monitoring of carbon fluxes it would be useful to assess wood decay. This may be especially important in the cyclone prone forest of the northern part of the Makira Complex where substantial amounts of standing dead wood may constitute a more stable carbon pool as intuitively assumed.

5. METHODOLOGICAL GUIDELINES

5.1. Delimiting the Forest Area for Estimating and Monitoring the Carbon Pool

Initial Remark: This task has been conducted.

The preliminarily identified project region is part of Madagascar's Eastern Rainforest corridor and includes the Makira plateau and the forests that extend way North to the Anjanaharibe-Sud protected area. In the south, the Rantabe River that crosses the corridor from West to East and where heavy "tavy" invasions have practically severed the eastern rain forest corridor delimits the region. In the West, the area is delimited by the semi-stable range agriculture frontier. In the southeast, the deforested coastal strip with its progressing easterly "tavy" frontier, extending quite far into the mid-elevation forests of the Makira plateau along the valleys, constitutes the limit. In the northeast, the limits extend to the East into an area of hurricane-prone forests around the upper watershed of the Andranofotsy River that bends far into the western plateaus. In the North, the project area includes all lands that constitute the biological corridor extending to the Anjanaharibe-Sud protected area. Note that the exact boundaries of the project region remain to be delimited based on the biological, socio-economic, political, managerial and logistic aspects of the future conservation-carbon sequestration project.

Within this project region, an extend track of land covered by continuous, little-impacted primary and near-primary forests still exists. It is this **core area** that was defined as the lands suitable for carbon sequestration calculations because it is believed that within this core area future "tavy" expansion could be contained by the carbon project. Hence, it is hypothesized that, based on good project management, it is feasible to maintain the standing carbon values of these steady-state forests (landscape-level, dynamic equilibrium) based on "tavy" intrusion avoidance. Hence, the core area is seen as the low-risk, available carbon baseline pool, feasible to be sequestered. In contrast, and because of high risks, the surrounding active slash and burn areas ("tavy"), and the areas in which more "tavy" are expected in the next years were excluded from this carbon estimation exercise deliberately limited to the low-risk core area at this stage. This, however, does not mean that active "tavy" containment activities should be excluded from this buffer area witch is part of the project region. At the contrary, it is within this buffer area that the major deforestation avoidance activities need to be conducted, but to be conservative (and realistic), only in light of conserving the core area. The forest fragments that would be conserved within this buffer zone must be seen as an unexpected, additional bonus that should only be accounted for in the carbon sequestration balance if achieved *de facto*.

The identification of this core area was conducted by scrutinizing a composite of two LANDSAT TM pictures taken in 1996. The pixels that fall into primary and near-primary forests display a red and reddish reflectance that contrasts with areas of slash and burn activities with a distinguishable whitish reflectance. Following a best-guess contour line of the slash and burn ("tavy") frontier, the deforested lands not suitable for carbon sequestration calculations were excluded, i.e., all "tavy". To accommodate for the likely expanding slash and burn activities around the photographed clearings since 1996, an additional safety buffer of approximately 1 km or more of intact forestlands was excluded. Major "tavy" islands within the intact forest matrix were identified and also encircled based on the same "tavy" expansion assumption. In a second operation, a more conservative delimitation based on a geometric pattern of horizontal and vertical lines was fitted within the initial contour, hence drawing the frontier edges even more conservatively. In addition, and based on observations and photos made during the two reconnaissance flights (Berner and Rarivoarivelomanana 2001, Berner 2001 b, Berner 2001 c), several larger areas of forests believed to be under considerable potential pressure were also excluded. This geometric perimeter is being considered as to encompass the forests suitable for carbon sequestration calculations.

5.2. Stratification

The stratification has to be conducted over the entire core area. A first-level stratification should be based on a coarse elevation limit set at 800 meters. The 800 meters level is a traditional cut-off elevation for vegetation classification as advocated by various botanists (Lowery et al. 1997). The limit is easily determined from the available FTM topographic maps.

The second-level stratification should be based on sub-regional, geomorphological features including: a) The rolling hills of the western frontier with their contrasting forests on hill-top and valley-bottom due to a dryer hydrological regime and differential soil depth. b) The high canopy forests of the central parts of the Makira plateau with their less conspicuous structural dichotomy between hill-top and valleys. c) The escarpments of the east and north-east with the falling cliffs, the canyons and landslide-prone slopes. The coarse delimitation of these strata is best achieved by using the early set of black and white aerial photographs produced by FTM and by verifying the strata boundaries with the available geo-referenced pictures from the reconnaissance flights.

The third-level stratification should be based on geological substrate whereby the spatial heterogeneity of the bedrock of the Makira Complex should be identified. Emphasis should be given to ultra-basic, marble and quarts outcrops that are likely to produce azonal forests with particular structure and composition with implications on biomass and carbon pools as well as on dynamics. These strata are best identified based on geological maps and mining exploration reports available at the Ministry of Mines and Energy.

The fourth-level stratification should take structural differences caused by natural disturbances into account and should stratify the forest according to cyclone damages. The distribution of these cyclone-damaged forests should be assessed form the pictures taken during the reconnaissance overflights and should be verified with additional ground-truthing flight.

A final stratification scheme of the Makira Complex should result from combining the different stratification patterns as described above. The final draft map should be compiled through an overlaying process. This map draft should then be verified through additional reconnaissance flights during which specific geo-referenced areas of uncertainties are verified.

The main difficulty of this approach consists in reconciling forest heterogeneity occurring at different scales. In fact, some of the stratification criteria proposed here, like altitude or geology produce strata that result in relatively homogeneous, large units (perimeters), easily mapped. In contrast, cyclones and topography bring about forest types that display a within stratum heterogeneity (e.g., lower strata hierarchy such as windward versus leeward or hilltop versus valley bottom). The spatial arrangement of this fine scale heterogeneity may result in a complex more linear or dendric matrix not readily mapped. For instance, a cyclone prone forest may display contrasting forest types between the windward and the leeward side of crests (Birkinshaw et al. 2001). Likewise, forests on rolling hills contain a complex matrix of alternating hilltop and valley bottom forests over a small range.

In order to tackle this stratification scaling problem it is proposed to proceed as follows: Biomass values within each stratum over the entire core area should be assessed from an array of permanent nested plots systematically arranged over transects. If a stratum, however, contains a lower-level within stratum heterogeneity (forests on rolling hills, cyclone-prone forests) the lower-level stratum (e.g., "hilltop", "valley bottom", "severe windward", "moderate leeward") the lower-level status should be identified at each plot and reported on a map. With this point-map a lower-level stratification map could be generated ***at posteriori*** with the help of software designed to conduct spatial extrapolations from grid points (e.g., software used to identify ore bodies from a grid of drilling hole data). With the lower-level stratification map, an assessment of the spatial partitioning of the lower-level strata can be generated. Hence, a typical assessment would look like follows: The rolling hill strata contain 60 % of valley bottom forests and 40 % of hilltop forests (fictive example). The average per hectare biomass and carbon values could then be computed for each lower-level stratum. The computing of the biomass for the entire strata would then be conducted by extrapolation the per hectare lower-level strata values in proportion to their spatial occurrence over the entire strata.

5.3. Estimating Forest-Level Biomass and Carbon Hectare-Values

The approach consists in assessing biomass and carbon per hectare values for all carbon pools by strata (some experimentally and others by using peer reviewed references) and multiply these averages by the surfaces of the respective strata in order to get biomass and carbon totals for the Makira Complex. The inventory design consists in establishing a grid of transects within each stratum along which sample plots are arranged systematically.

5.3.1. Pilot Study for Sample Size Establishment

Since reliable biomass or soil carbon data are not available for the Makira Complex pilot studies will have to be set up to estimate variances and calculate sample size by strata. Within each stratum, 12 circular plots of equal area (between 250 and 500 sq. meters) will serve as preliminary samples. Based on a nested design, above-ground trunk biomass, understory biomass, litter crop, soil carbon and below-ground biomass will be assessed. Cost and implementation time will also be recorded.

The pilot study will serve as a training exercise and should help providing final figures for the budgeting and scheduling of the field inventory and monitoring (assessment of time and costs). Once the preliminary figures are known, the level of precision should be stated under consideration of the available budget. A pragmatic tradeoff between precision, cost and time will have to be found. If the overall carbon assessment budgeting is required before the pilot study can be conducted a conservative sample size figure utilized for budgeting only should be assumed based, for instance, on the Noel Kempff experience. In this case, a minimum of several hundred plots per strata should be accounted for in order to provide an acceptable baseline even under the tightest budget. Nevertheless, the pilot study needs to be conducted in any case.

5.3.2. Above-Ground Woody Biomass

Permanent circular plots will be established along transects within each strata. Adequate plot size can be adjusted using the results from the pilot studies. Optimal plot size can be somehow estimated. It is approximately proportional to plot size used in pilot study, directly proportional to the square of the travelling time between plots and indirectly proportional to plot measurement time (MacDicken 1997). Meanwhile, circular plots with radii over 10 meters are not suited for the Makira Complex because of the poor visibility encountered in dense to moderately dense woody vegetation. A plot size of 400 square meters seems adequate.

The circular, permanent plot design will permit the assessment of the above-ground woody biomass predominantly based on a forestry-type inventory for the big trees. First, trees with dbh >= 10 cm will be identified, tagged and measured (dbh and heights) over the entire plot. With a nested circular plot design, smaller trees between 5 and 9.9 cm dbh and trees from 4.9 cm down to 2 cm dbh will be measured. The radii of the smaller concentric circles will be established during the pilot study (function of unknown understory tree densities). From these measurements of trees that include all diameter classes down to 2 cm dhb the VOB (volume over bark) values will be computed. No destructive sampling within the permanent plots will be required and the plots (or a subset of them) can be used for periodic monitoring.

Form Factor, Wood Density and Biomass Expansion Factor: If forestry-type data is generated, trunk biomass density needs first to be calculated from VOB/ha values. Then, the inventoried value has to be "expanded" to take the biomass of the other above-ground components into account (branches, twigs and leaves) (Brown and Lugo 1992). Form factor, wood densities and BEF (biomass expansion factors) are needed to compute biomass from VOB (BEF is defined as the ratio of above ground oven-dry biomass of trees to oven-dry biomass of inventoried volume). If form factor, wood density and BEF are not available, the following alternatives must be considered:

- Develop the factors (most precise and costly approach).
- Develop factors for a group of plants (morphological grouping) and for the most important carbon pools (e.g., branches).
- Use available factors from the literature.

For the Makira Complex the following approach is advocated:

- Form Factor: Use conservative values as recommended by ESSA-Forêts and verify their general agreement with peer reviewed recommendations.
- Wood Density: Use values for the available species as proposed by FO.FI.FA. Group all trees by wood-density guilds (e.g., dense, moderate, soft), and assume conservative density averages for each guild (watch out for conversion factors for different moister contents as density was determined (Reyes et al. 1992)). Report associated guild when measuring trees during inventory in order to have a tree-by-tree density estimate.
- BEF: Given that no reliable average above-ground oven-dry biomass values of trees are available for the eastern forests of Madagascar it seem appropriate to conduct a study to verify the reference values proposed for other sites). Hence, it is recommended to conduct a destructive biomass tracking exercice (DEBIT) to assess a baseline BEF value for eastern Madagascar. The study should be conducted in a forest fragment outside of the perimeter of the project.

5.3.3. Above-Ground Understory Biomass

Above-ground understory biomass includes all residual plants that are not taken into account in the above-ground small tree biomass component because of their small size, (i.e., saplings (< 2 cm dbh), seedlings, herbaceous plants, ferns, mosses etc. Estimating the biomass of this component includes destructive sampling in small plots that should be part of the DEBIT exercise.

5.3.4. Below-Ground Biomass

Root biomass is an important carbon pool that is difficult to estimate even at moderate levels of precision. Given, however, that there is no supporting data for the Makira Complex and because assuming conservative values would lower the assumed below-ground carbon pool below a desirable threshold, it will be necessary to produced baseline values through sampling. Hence, it is recommended to conduct a core sampling exercise at the edge of the permanent plots along the transects until a satisfactory level of precision (variance) is reached. The sampling should be conducted with a split-core corer of 80 mm diameter inserted manually at depth of 30 cm or more (consult Indian Ocean literature and propose a design that permits comparisons with values produced elsewhere in this part of the world).

5.3.5. Soil Carbon

Soil carbon constitutes a substantial fraction of the total carbon stock of a tropical forest. Soil carbon relevant for the Makira-Complex should be limited to organic carbon. Organic soil carbon backup values should be produced by an independent study conducted by the soil department of ESSA-Forêt. The soil sampling exercise should be conducted in tandem with the below-ground biomass assessment discussed above. Use an established soil carbon laboratory procedure available in Madagascar (Walkley-Black).

5.3. 6. Litter Crop

Litter crop includes fine litter and dead wood. Fine litter constitutes a relatively small fraction of the above ground biomass and should only be collected to provide a backup baseline value for the Makira Complex. Hence, a sub-sample of frames should be put at the edge of each permanent plots along the transects until a satisfactory level of precision (variance) is reached.

Dead wood is likely to constitute a substantial fraction of the above-ground carbon stock and values from the literature display large ranges. In order to narrow down the range, it is recommended to investigate the dead wood fraction of the Makira Complex. In addition, and in conjunction with the monitoring of carbon fluxes, it will be necessary to assess wood decay. This is especially important in the cyclone prone forests where substantial amounts of standing dead wood is substantial (Birkinshaw et al. 2001).

6. ACTIVITY CATALOG FOR FIRST-APPROXIMATION BUDGETING

1) Delimiting the Area for Estimating and Monitoring the Carbon Pool

- Purchase updated satellite images
- Identify the updated "tavy" frontier (geometric perimeter)
- Produce baseline topographic maps of core area
- Elaborate slope maps of core area

2) Stratification

- Map first-level stratification (800 m)
- Map second-level stratification (geomorphology)
  - Get FTM black and white photos
  - Verify strata boundaries
- Map third-level stratification (geology)
  - Get geological maps
  - Get mining exploration reports
  - Delimit boundaries
  - Verify findings with peers
- Map fourth-level stratification (natural disturbances)
  - Get maps of past cyclone paths
  - Analyze available photos
  - Assess lower-level stratification patterns (i.e., windward -leeward)
  - Verify findings
- Overlay maps and propose stratification
- Conduct verification overflights
- Refine and produce small-scale stratification map
- Assess strata surfaces

3) Preliminary Project Design with Sponsor

- Discuss issues with sponsor
- Define sample frame with sponsor
- Define basic sampling design (stratified random) with sponsor
- Define precision level with sponsor

- Draft sampling and monitoring guidelines
- Define monitoring schedule with sponsor

4) Pilot Project
   - Design pilot project
   - Design training module
   - Produce sampling protocols
   - Conduct site identification
   - Recruit participants
   - Organize logistics
   - Execute on-the-job training (6 strata with 10 to 12 plots each)
   - Collect data
   - Analyze data and calculate variances

5) Final Project Design, Accessibility Mask and DEBIT design
   - Identify accessibly mask for each stratum
   - Define outline of transects within each stratum
   - Identify plots sample size for each strata
   - Produce strata-level maps with sample sites
   - Provide GPS lists for plot identification
   - Design Destructive Biomass Tracking exercise (DEBIT)
   - Identify site of DEBIT
   - Define working organization (hierarchy)
   - Define camp sites organization
   - Formulate sampling protocols
   - Conceptualize data flow and monitoring
   - Draft sampling guidelines

6) Logistical Supply Plan and Equipment
   - Compiling equipment lists
   - Ordering and buying equipment
   - Receiving equipment (custom)
   - Define implementation schedules
   - Define camp sites schedules
   - Conduct supply plan verification overflight
   - Refine logistical plan
   - Transport of crews and equipment
   - Crew supplying
   - Organize communication (satellite phone)

7) Setting Field Inventory and DEBIT

- Recruit final team (team leaders Tana)
- Set base camps
- Conduct final hands-on site training at DEBIT
- Organize teams (matching)
- Recollect samples (DEBIT)
- Analyze samples
- Compile data of DEBIT

8) Above-Ground Woody Biomass

- Send teams out
- Establish camps at strata
- Prepare transects
- Locate plots (6 strata 80 plots)
- Collect data

9) Above-Ground Understory

- Conduct undestory assessment
- Calibrate assessment with values from DEBIT

10) Below-Ground Biomass and Soil Carbon

- Set up root preparation camps
- Conduct root coring
- Organize shipping of root material
- Sent root material for analysis
- Analyze roots
- Collect soil cores
- Organize shipping of samples
- Sent to laboratory
- Compile data

11) Litter Crop

- Make litter frames
- Place and monitor frames
- Prepare litter material for biomass assessment
- Collect dead wood data
- Set up decay study

12) Data analysis
- Set up data analysis lab in Tana
- Purchase computers and software
- Train people
- Organize data flow
- Organize data checking with field crew
- Produce compiled results
- Publish results

7. BUDGET

7.1. Fixed Costs (largely independent on sample size)

- Delimiting the Area for Estimating and Monitoring the Carbon Pool
  - $ 1000.-
- Stratification
  - $ 6500.-
- Preliminary Project Design with Sponsor
  - $ 4000.-
- Pilot Project
  - $ 25000.-
- Final Project Design, Accessibility Mask and DEBIT design
  - $ 12500.-
- Logistical Supply Plan and Equipment
  - $ 37000.-
- Setting Field Inventory and DEBIT
  - $ 54000.-
- Total
  - $ 140000

7.2. Variable Costs (depending on the number of plots)

- Above-Ground Woody Biomass
- Above-Ground Understory

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- Below-Ground Biomass and Soil Carbon
- Litter Crop
- Data analysis
- Total (6 strata with 80 plots $ 500.-)
  - $ 240000.-

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